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A RISK ASSESSMENT APPROACH FOR PRIORITISING STORMWATER CONTROL STRATEGIES

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Abstract

An important element in considering alternative drainage strategies and options (and their subsequent implementation and management) is an assessment of associated risks and uncertainties. As a contribution to meeting this typically 'wicked' challenge, this paper presents a structured and systematic approach to evaluating data and information from a range of sources within a single framework which can be developed and applied using site or catchment specific information. This approach is described in detail and involves the development of 'risk scores' which enable identified risks to be prioritised, or ranked. The completion of this process provides a platform for the consideration of risks which may apply over a range of time-frames, providing an opportunity for risks identified to be addressed within current and/or longer-term urban planning policy and regulatory developments. The application of the approach in relation to an assessment of risks to stormwater planning associated with the Eastside Development, Birmingham, UK, is briefly discussed.

INTRODUCTION

The widely predicted future scenario of climate change, uncertain economic and socio-political conditions combined with potentially significant legislative, regulatory and institutional changes will inevitably lead to a variety of both risks and opportunities with regard to the implementation and management of UK urban surface water drainage infrastructure (Ellis and Revitt, 2009). As stated in both the Pitt report (Pitt, 2008) and in the UK government review of surface water drainage (Defra, 2008), the immediate future priority objectives will be to avoid or minimise increased flooding and associated pollution risks whilst at the same time achieving increased cost-performance efficiency and enhancement of the local environmental quality-of-life. Identification of, and mitigation options for, the principal threats and uncertainties associated with the achievement of integrated urban stormwater management (IUSM), within the context of both contemporary and future environmental, institutional, legal and socio-political conditions for a variety of demonstration cities, forms a prime objective of the EU 6th Framework SWITCH project (www.switchurbanwater.eu). Preliminary work founded on database surveys conducted in collaboration with local Learning Alliance (LA) stakeholder groups established in Birmingham, UK, Belo Horizonte, Brazil and Hamburg, Germany (Ellis *et al.*, 2008a) and which has provided an appropriate basis for a detailed risk assessment analysis. This current paper describes the structure and development of a risk rating procedure to support stakeholder evaluation of the relative strengths and vulnerabilities of different stormwater control systems and management approaches under varying identified future scenarios. The developed risk assessment matrix not only considers the threats and uncertainties associated with flooding and pollution risks, but also with risks associated with receiving water ecology, urban landuse planning, surface water management strategies and differing BMP/SUDS control approaches.

A RISK ASSESSMENT APPROACH

A framework structure

A risk assessment approach for urban surface water management must take place within the context of the principal system performance attributes which can be defined by source flooding, water quality, conveyance terms and receptor impact terms as illustrated in Figure 1. Whilst such a framework may provide an appropriate structure for the evaluation of risk likelihood and impact consequences, it is reasonable to question whether cost-performance should constitute the central, universal risk indicator. Is it acceptable to develop a risk evaluation framework where stormwater control options and strategies are to be prioritised exclusively on the basis of expected damage costs? A definition of risk as the product of component/asset value x threat x vulnerability places equal importance on each of these criteria, but it must be assumed that costing will comprise a major driver for urban stormwater management. In addition, it is not clear how uncertainties will be expressed within such a framework approach. There is also a need to ensure that risk evaluation is applied to infrequent, high magnitude storm exceedance conditions for pluvial flood management and to high frequency (<1:1 RI), low magnitude rainfall events for diffuse non-point pollution management. The need for a risk assessment framework cannot suppress the real and fundamental question for urban surface water management which is

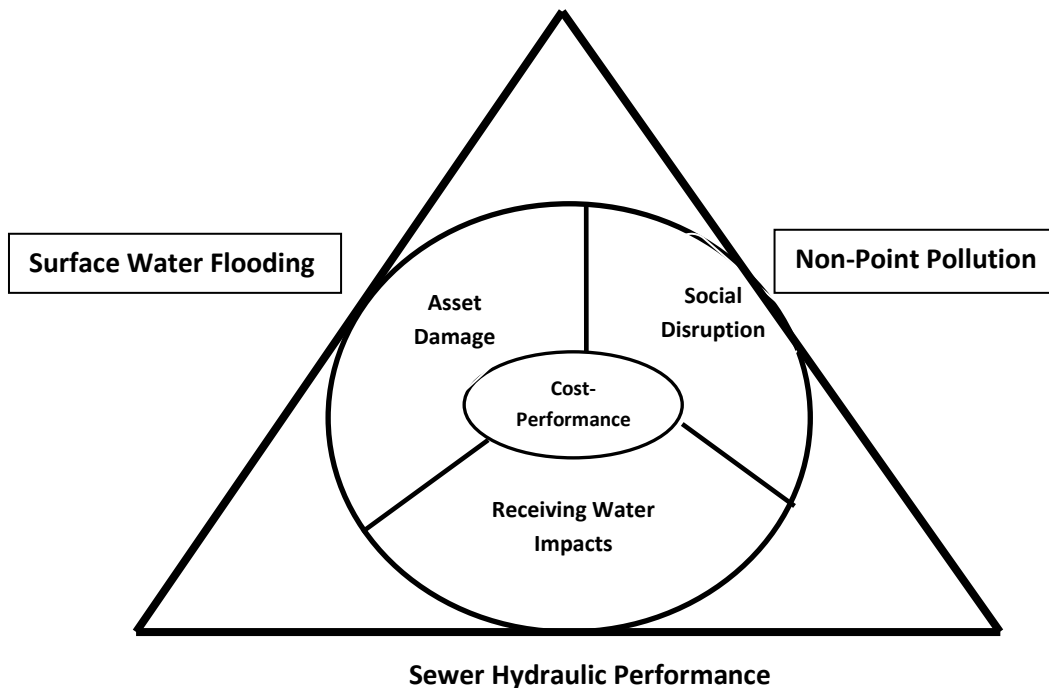


Figure 1. Framework structure for surface water risk assessment

what and *where* to design and implement mitigating measures. This fundamental question has been addressed elsewhere within a previous EU 5th Framework DayWater project (Ellis *et al.*, 2008b), and which is also the basis for the similar US EPA BMP process and placement SUSTAIN model (Lai *et al.*, 2007). However, what is abundantly clear from many urban surface water studies is that success or failure of stormwater control strategies is much more dependent on institutional and policy structures and decision-making processes (as well as perhaps model mis-application), than in any inherent technical constraints or data limitations.

It is also relevant in this framework structure to distinguish between inherent and residual risks. The former directly measures the likelihood and consequences of damage resulting from a hazard when no or limited mitigating controls are in place whereas the latter takes strategic implemented controls into account. Percentage residual risk identifies that proportion of a risk that remains “unmanaged” despite the mitigating controls being in place and is measured as: % Residual Risk (R_r) = [Residual Risk (R_r) / Inherent Risk (R_i)] . 100

Acceptable cost-effective performance risk reduction can normally be achieved at levels of up to 50% residual risk, although lower threshold levels (e.g 20% or 30%) may be more appropriate standards as a best practice target. In one sense, the application of residual rather than inherent risk also incorporates some consideration of uncertainty into the framework structure. Despite inherent risks in surface water drainage having generally increased over time due to rapid urban expansion, low investment, climate change etc., the residual or actual damage risks have not increased proportionally. This reflects the improvements that have come about from better and more robust drainage infrastructure, stricter regulatory standards and improved management practices over the last decade. However, it must be borne in mind that risk assessment is as much a tool or approach for stakeholder communication and learning as it is about quantitative condition evaluation and risk management.

A risk assessment matrix

A risk assessment procedure typically involves four stages; identification of hazards, assessment of the consequences (or severity) of the hazard occurring, assessment of the likelihood (or probability) of the hazard occurring and finally, a combination of the above information into a single value representing the level of risk associated with the identified hazard. The assessment of both the severity and likelihood of an identified threat occurring generally involves assessing an information or data set using an appropriate relative scale e.g. 1 to 5, where the numeric values have been pre-defined to represent either a comparatively escalating severity of consequence or likelihood of occurrence (see Figure 2). The consequence severity reflects the vulnerability of the asset or management component to damage, whilst the likelihood represents the probability of the particular

threat event or level occurring. Such a risk assessment approach is well recognised and accepted (e.g. CRAMM, 2003; USDA, 2003) and has the advantage that it enables the overall assessment procedure to be more objective as well as allowing aspects to be handled that are not strictly governed by explicit numeric values. Although the use of quantitative data is preferred, this approach recognises that neither the impact nor the likelihood of an identified event occurring can always be readily quantified, if at all. Hence, this methodology also supports the use of more qualitative data and the use of ‘expert judgement’ which, in the absence of field or literature data, is recognised as a pragmatic approach to managing the need to make decisions in the face of uncertainty (Scholes *et al*, 2008).

Once this information has been compiled, it can then be used to prioritise the identified risks, effectively developing a ranked order of risks based on a combination of the severity of a particular risk occurring together with its likelihood of occurrence. A common approach to the combination of these two sets of data is the development of a matrix which enables both sets of data to be viewed simultaneously in a format which readily supports the application of an initial approach to risk rating such as that used by the England and Wales regulatory body, the Environment Agency (DETR *et al*, 1995), based on an initial 5 point scale, with subsequent combined risk values categorised as low, medium or high in relation to scores of 1-5, 6-11 and 12-25, respectively (see Figure 2); extreme values are considered to exceed 16.

This type of 3-level interpretation of risk scores is commonly described as a ‘traffic light’ approach when the colours red, yellow and green (as opposed to dark grey, medium grey and light grey as in Figure 2) are used to support users in differentiating between risk levels and in terms of serving as ‘trigger’ or threshold levels for management actions. The development of such a risk assessment matrix, and the subsequent risk rating procedure, can thus provide an appropriate framework to facilitate decision-making processes based on an initial screening technical risk assessment. This approach is also appropriate in terms of facilitating the involvement of a variety of stakeholders drawn from technical, administrative and public community sectors. Full detail of the guideline procedure is given in Ellis *et al* (2007).

		Severity of consequence				
		Insignificant (1)	Minor (2)	Significant (3)	Damaging (4)	Critical (5)
Likelihood of occurrence	Very Low (1) (Rare)	1	2	3	4	5
	Low (2) (Unlikely)	2	4	6	8	10
	Medium (3) (Likely)	3	6	9	12	15
	High (4) (Frequent)	4	8	12	16	20
	Very High (5) (Chronic)	5	10	15	20	25

Interpretation of overall risk: High = 12-25 (dark grey) with >16 being Extreme; Medium = 6-11 (medium grey); Low = 1-5 (light grey).

Figure 2. Matrix used to evaluate the level of risk

THE SWITCH STORMWATER RISK MATRIX

To ensure clarity, it is essential that hazards or asset threats are unambiguously and precisely identified, and that classifications of impacts and frequency of occurrence are supported by brief statements justifying the allocation of one value in comparison to another. This process may be to some extent iterative, with the threats and uncertainties originally identified by stakeholder groups requiring refinement to more precisely identify a particular aspect of an identified threat which is being considered. For example, the threat of ‘increased frequency of storms’ could require further refinement if both the increased frequency of increased intensity storms and the increased frequency of storms having no change in intensity were of interest to stakeholders.

Assessing the consequences of system failure

In assessing the potential impact of an identified failure occurring, the answer is sought to the question “what will happen if the system or system component fails to act/serve as intended?” A pre-requisite to answering this question is a knowledge or statement of the expected level of performance which may be clear and unambiguous for some aspects of the stormwater management system, e.g. a swale designed to protect a highway from

flooding by a storm event of up to a 30 year return period. The consequences of such a failure can be estimated in terms of the costs (direct and indirect) incurred as a result of sub-base flooding and erosion, if appropriate. The failure of a wetland to achieve a specified pollutant removal level e.g. annual average concentration (mg/l) per annum target, can similarly be quantified in terms of the costs required to increase the retention capacity combined, perhaps, with the costs of correcting downstream damage or the enhanced treatment required to re-establish receiving water standards. In other cases, the performance objective may be more ambiguous e.g. in providing an amenity function for a particular stormwater control device it may only be possible to express values in relative terms such as allocations of high, medium or low values. However, a grading level for the consequences of system failure can be constructed which can support classifications based on either absolute or relative estimations i.e as inherent or residual risk values.

In relation to the development of the SWITCH risk matrix, Table 1 provides guidance which the various stakeholder Learning Alliance groups in the selected demonstration cities were asked to use to support the consistent assessment of the consequences of a particular identified threat occurring.

Table 1. Guide to assessing the level of consequence of an identified threat/uncertainty occurring as entry to the SWITCH stormwater matrix

Level of consequence (Grading)	Example descriptors for relative grading	Numeric value associated with grading level
Very high consequence	<i>Critical or Catastrophic:</i> complete system compromise; unacceptable under any circumstances; disaster level; loss of life; extreme cost	5
High consequence	<i>Damaging or Major:</i> Substantial failure to meet regulatory requirement; substantial impact such as flooding of properties; temporary loss; considerable cost	4
Medium consequence	<i>Significant or Moderate:</i> potential to cause political, administrative and/or financial strain or pressure; tangible damage; can be managed under most normal procedures	3
Low consequence	<i>Minor:</i> minimum impact; some additional costs/efforts required but consequences readily absorbed although some management effort required to minimise impacts	2
Very low consequence	<i>Insignificant:</i> negligible or no impact felt and not worth taking further action	1

Example descriptors given in Table 1 in relation to a particular level of consequence or vulnerability are not meant to be exhaustive, but to generically illustrate the types of escalating impact which could be associated with the allocation of a particular categorisation. The numeric values given to each consequence grading are not necessarily intended to reflect a linear escalating scale of consequence or severity, such that a value of 4 is twice as severe as that allocated a value of 2. The numeric scaling may be linear but could also be applied in either a positive or negative exponential manner. Users should be aware of the general relationship between the numeric values being allocated to specific gradings and be prepared to justify the scaling used.

Assessing the likelihood of a failure

In assessing the likelihood of an identified failure occurring, it is necessary to identify how often a particular feature or component is likely to fail. Once again, a pre-requisite to assessing the likelihood of a failure to occur is knowledge of the expected or targeted level of performance of the stormwater management system or component. This might be addressed by available published data, historic evidence, expert judgement or modelling etc. For example, hydrologic modelling of a swale designed to contain the 1: 30 year runoff event would be expected to fail each year with a probability of 0.033. This level of failure might then be graded as being of low significance as it clearly meets the desired criteria or standard of protection. However, if the channel only achieves in practice a 5 year level of protection, then the probability of failure in any one year rises to a 1:5 frequency (or a probability level of 0.20) and this might then be regarded as being of at least medium significance. In the absence of data or predictive models (or where there is a large degree of associated uncertainty), the use of collective expert judgment is recommended as a pragmatic approach.

With regard to the SWITCH stormwater risk matrix, Table 2 illustrates the guidance provided for the demonstration city Learning Alliance stakeholders in support of a more consistent assessment of the likelihood of a particular identified threat or failure occurring. The generic example descriptions given in Table 2 again only describe how a range of 'likelihood of occurrence' data might be comparatively graded. As with the scaling

ratio applied for consequence, the numeric values assigned to the gradings for ‘likelihood of occurrence’ can be linear or non-linear in distribution.

Table 2. Guide to identifying the likelihood of occurrence of an identified threat/uncertainty within the SWITCH stormwater matrix

Likelihood of occurrence (Grading)	Possible descriptors for relative grading	Numeric value associated with grading level
Very high probability	<i>Chronic Failure:</i> Almost certain to fail to meet required criteria during anticipated design life; failure during every wet weather event	5
High probability	<i>Frequent Failure:</i> High likelihood to fail to meet required standards; frequently fails during storm events e.g on perhaps bi-monthly basis	4
Medium probability	<i>Likely Failure:</i> May not meet required standards; failure will occur at some time i.e once in a while	3
Low probability	<i>Unlikely Failure:</i> Normally meet required standards throughout design life but failure could occur at some time	2
Very low probability	<i>Rare Failure:</i> Unlikely to fail during lifespan; failure only under very exceptional circumstances	1

RISK RATING

The level of risk can be assessed by combining information generated on likelihood of occurrence (Table 2) with information developed on the level of consequence (Table 1). One approach is to multiply together the numeric values associated with each of the identified relative gradings (see Figure 2) generating a ‘risk score’. The resulting overall level of risk associated with a particular threat or uncertainty can then be interpreted using a pre-established scale, such as that included in Figure 2. A simple sensitivity analysis can be applied by examining the behaviour of the model through examining the variability in risk outcomes arising from variations in stakeholder preferences and priorities, which can then be used to test the robustness and reproducibility of the procedure. The risk rating given in the assessment matrix provides a measure of the overall risk potential in a realistic worst-case scenario. Activities, hazards or impacts areas carrying the highest total inherent risk should be regarded as “unacceptable” and in need of urgent management attention regardless of how robust the controls in place are thought to be, since major problems and damage would result if the preventative systems were to fail. Thus individual hazards having threshold risk scores greater than 16 should require immediate mitigating options to be developed and put in place. An issue can arise where the methodology deems risk levels and impacts to be “acceptable” where they result in low scores e.g ratings of 3 – 4 in Figure 2, and thus for which no risk reduction or mitigation measures are recommended. For such ambiguous risk situations, a “discourse-based” stakeholder strategy might be considered to help create a mutual understanding and acceptance of any conflicting views and values. Irrespective of these reservations, a matrix rating procedure combining the likelihood of occurrence with the severity of the consequences of identified threats can be used as a basis for visually illustrating the level of risk posed by each system component/aspect. This approach can then provide a useful contribution to subsequent stakeholder discussions and decision-making within the development of a risk management strategy.

APPLYING THE RISK ASSESSMENT METHODOLOGY

The risk assessment matrix has been applied and tested for identified threats and uncertainties associated with urban surface water management for the 140 ha Eastside re-development area in the city of Birmingham, UK. Parameters considered to be critical in stormwater management by the local stakeholder Learning Alliance members included flooding, water quality, receiving water ecology, urban landuse planning, BMP/SUDS controls and surface water management policy/administration. Matrix rating scores were developed for all these six criteria, for both prevailing contemporary conditions as well as extrapolated for the city-of-the-future in 25 to 30 years time. Some indication of the benchmarking criteria for the flood risk component is shown in Table 3 which indicates the guidance for evaluating the likelihood and consequence scores for the risk matrix. Full detail of the methodology, testing application and outcomes is given in Ellis *et al.*, (2008a).

Key methodological questions include how risk scores should be assigned for such multiple benchmarking and the differences associated with adopting differing scales as well as how criteria themselves should be benchmarked. For example, is it more appropriate to consider the consequences of flood hazard in terms of flood depth, cost-damage function or numbers of properties flooded? What difference does such choice mean for the ultimate matrix rating and for the residual risk? In addition, it is not always clear how qualitative data from a diversity of sources can be meaningfully

Table 3. Flooding criteria and benchmarking for Birmingham Eastside

Threat or Uncertainty	Failure Likelihood	Failure Consequences	Possible Risk Mitigating Approaches
Flooding	Increased and more frequent summer storm intensities; increased overland pluvial flows. Backing-up of surface water outfalls/drains by river flooding. Ageing sewer infrastructure; insufficient hydraulic capacity (normally <600 mm); surcharging during extreme events (>1:20). Urban creep and re-development extending impermeable surface area.	Routing of overland exceedance flows along street and gutter pathways. Flood damage/nuisance to properties, local traffic, pedestrian access etc. (flood depth, cost-damage, properties flooded). Blockage and damage to surface water outfall flaps. Blockage of gullies and surface drains.	Improved modelling methods (1D/2D overland flow path modelling). Full implementation of PPS25 for retrofit, new development and flood prone areas. Development of local SWMP. Integrated inter-agency agreements and approaches. Introduction of source BMP/SUDS controls.

integrated with “hard” quantitative engineering data without losing methodological transparency and the trust of stakeholders. In this respect, the assessment procedure can be susceptible to valued judgements, and the scientific appraisal of failure consequences can frequently be biased towards a technocratic assessment of system/component condition. Implementation of risk analysis can be difficult and contentious, especially when quantitative “opinion-based” input is involved. This can render the outcome potentially dependent on subjective experience which can result in bias and inconsistency. Nevertheless, risk rating provides a structured and well established methodology capable of rapid screening and delivering a good stakeholder communication and discourse tool for the identification of priority concerns and possible mitigating approaches for urban stormwater management.

For the Birmingham Eastside test area, the most significant risks and associated uncertainties arise from inadequacies in existing drainage capacity and source mitigating controls, especially in terms of appropriate management of overland exceedance flows from impermeable surfaces. These risks are due to a combination of deficiencies in technical, planning, administrative and policy attributes and functions which require attention and integration of local, regional and national strategies for urban drainage infrastructure provision and management in order to be addressed in a successful and sustainable manner.

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